

CHAPTER 34

Human Space Flight

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1. UNIQUE FACTORS IN SPACE FLIGHT

1.1 Introduction

The first human space flight, in the early 1960s, was aimed primarily at determining whether humans could indeed survive and function in micro-gravity. Would eating and sleeping be possible? What mental and physical tasks could be performed? Subsequent programs increased the complexity of the tasks the crew performed. Table 1 summarizes the history of U.S. space flight, showing the projects, their dates, crew sizes, and mission durations. With over forty years of experience with human space flight, the emphasis now is on how to design space vehicles, habitats, and missions to produce the greatest returns to human knowledge. What are the roles of the humans in space flight in low earth orbit, on the moon, and in exploring Mars?

(insert Table 1 about here)

1.2 Gravity

The most obvious factor specific to space flight is gravity. Orbiting the earth, crews experience free fall, or micro-gravity. This affects all aspects of life, and requires special considerations when designing habitat, equipment, tools, and procedures. During launch and entry, crews experience hypergravity for short periods of time. Extensive research and experience with high performance aircraft has provided great understanding of these environments, and indeed the tasks to be performed are similar to aviation tasks. On the surface of the moon and Mars, gravity is substantially lower than on Earth, but is definitely sufficient to allow designing habitats, equipment, and tasks analogously to the ones on Earth.

1.3 Mission Constraints

Accommodations for humans in space are constrained by the three major mission drivers: mass, volume and power. Each of these factors drives the cost of a mission. Mass and volume determine the size of the launch vehicle directly; they limit consumables such as

air, water, and propellant; and they impact crew size and the types of activities the crew performs. Power is a limiting factor for a space vehicle. All environmental features – atmosphere, temperature, lighting – require power to maintain them. Power can be generated from batteries, from fuel cells, or from solar panels. Each of these sources requires lifting mass and volume from Earth, driving mission cost.

1.4 Mission Duration

The habitability and human factors requirements for space flight are driven by mission duration. The Space Transportation System (STS) was designed for missions on the order of two weeks – analogous to a camping trip. With Mir and the International Space Station (ISS), mission durations of six months became standard, requiring far more concern for habitability and for crew efficiency, training, and sustenance. As NASA begins to plan for a mission to the Mars surface, with travel times on the order of six months each way and a possible surface stay of 18 months, it must address providing all support and services to crew members: health maintenance, training, recreation, food, clothing, etc.

1.5 Communications

To date, the model for space exploration has had a very small crew – from a maximum of seven or eight on a Shuttle flight, to just two people on the ISS – supported by a very large group of scientific and engineering experts on the ground. The crew and ground personnel are linked through the Mission Control Center (MCC). This model has been essential because such a small crew cannot be expert in all the critical subsystems on board. There are too few people to understand the subsystems in sufficient detail to operate and maintain them under nominal circumstances, let alone when malfunctions occur. But this model depends on rapid two-way communications. Video and audio transmissions allow the MCC to see and hear the crew, and to transmit questions and procedures in a short enough time to be responsive to time-critical events. Even on the lunar surface, communications lags are on the order of seconds. But with a mission to Mars, the nature of communications and the roles of the ground and flight crews will be reexamined to consider a delay of 20 minutes each way.

1.6 Crew Time

Crew time is becoming recognized as another mission driver. The size of the crew directly affects mass and volume requirements. Designing equipment and procedures to maximize returns from crew time is beginning to be considered in the earliest stages of mission planning.

Detailed studies of how crew time was actually used during Skylab (Bond, 1977) showed that approximately 1/3 of the crew time was spent in sleep, 1/3 in other forms of self-sustenance such as hygiene, exercise, eating, recreation, and 1/3 was actually devoted to operating the spacecraft and scientific experiments.

2. ANTHROPOMETRY AND BIOMECHANICS

2.1 Changes in Posture and Body Size

In a microgravity environment the body changes. Immediately on reaching free-fall, the body assumes a 'neutral' posture quite different from standing or sitting postures on Earth. The neck, shoulders, elbows, hips and knees all flex somewhat, and the shoulders also abduct and rotate with a large inter-subject variability. The result affects the crewmember's line of sight, height, and reach envelope. The range of postures observed on one Shuttle mission is shown in Figure 1. Table 2 gives the joint angles. Figure 2 illustrates reach envelopes based on a typical posture for a 95th percentile crew member.

After a short while, on the order of hours, the body height changes due to spinal elongation. Height increases about 3% during the first day or so in microgravity. The distribution of body fluids also changes. Greater amounts of body fluids move to the head and torso, affecting hand size, facial appearance, the voice, and perhaps the sense of smell. Space suits and gloves, which must fit snugly, must accommodate changes in hand size and stature.

(Insert Figure 1 about here)

(Insert Table 2 about here)

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2.2 Changes in Strength

Changes in strength over time in microgravity have been a focus of research because of the direct effect on ability to perform physical tasks. Jaweed (1994) reports significant (10 – 20%) decreases between the preflight and postflight strength in the antigravity muscles (back and legs) after as few as 5-10 days on orbit. This, taken with the loss of bone mass observed (Schneider et al., 1994) indicates that countermeasures must be taken for long duration flights and that tasks that can be performed early in flight might be more difficult or dangerous after extended time in microgravity.

The most common countermeasure for strength loss is exercise, particularly of the legs and back. Typical equipment includes bicycle ergometers and treadmills. When designing spacecraft, volume must be allowed for equipment storage and deployment. Significant periods of crew time, on the order of an hour per day per person, must be reserved for exercise. Design and location of equipment must address isolation of vibration and noise.

3. ENVIRONMENTAL FACTORS

3.1 Human Factors in a Closed Environment

NASA strives to close the spacecraft environment, in the sense that every effort is made to recycle air and water rather than to carry replacement oxygen and water on a mission. This greatly affects design of the habitat and equipment. Materials must not release compounds that are difficult to remove from the atmosphere; this eliminates a variety of plastics and certain types of finishes for other materials. Materials must be compatible with cleaning materials and biocides that are safe for the environment; they must be incompatible with flourishing colonies of bacteria and mold.

3.2 Atmosphere

Crewmembers in the system must be provided with an environment to enable them to survive and function as a system component in space. An artificial atmosphere of suitable composition and pressure is the most immediate need. It supplies the oxygen their blood must absorb and the pressure their body fluids require. Humans can survive in a wide range of atmospheric compositions and pressures. Atmospheres deemed sufficient for human survival are constrained by the following considerations:

- a. There must be sufficient total pressure to prevent the vaporization of body fluids.
- b. There must be free oxygen at sufficient partial pressure for adequate respiration
- c. Oxygen partial pressure must not be so great as to induce oxygen toxicity.
- d. For long duration (in excess of two weeks) some physiologically inert gas must be provided to prevent atelectasis.
- e. All other atmospheric constituents must be physiologically inert or of low enough concentration to preclude toxic effects.
- f. The breathing atmosphere composition should have minimal flame/explosive hazard.

Mission planning must take the above considerations for atmospheric conditions and balance them with the constraints of the mission: length of mission; mission objectives; requirement for pre-breathe (for ExtraVehicular Activity); research requirements for the mission; and equipment in the vehicle.

3.3 Water

In addition to the obvious need for drinking water, water is required for a variety of other uses. They include personal use, hygiene and housekeeping. If plants are to be grown during the mission, that is an additional water requirement.

Typical water requirements for drinking, hygiene and washing for each crewmember are 2.84 to 5.16 kg per person per day for standard operational mode. (NASA, 1995). A crew depends on water that is clean and safe. The use of water that is reclaimed and stored depends on its quality.

Water management systems changed with the design of the space vehicles and life support requirements of each program. During early Mercury, Gemini, and Skylab missions, water was filled up in tanks, built into the vehicle before launch and carried into space. However, during the Apollo missions, the water source came from the fuel cells; fuel cells convert hydrogen and oxygen to generate power with water as the byproduct. This marked a major breakthrough in the water management technology because water tanks did not have to be pre-filled before the launch. The Shuttle orbiter uses four 168-pound capacity steel tanks. The potable water source comes from the fuel cell byproduct, water. (NASA, 2004a) The excess water from the Shuttle is used to meet the water requirements of the ISS under normal mission configuration.

3.4 Noise

Noise can affect human physiology and health in a number of ways (Wheelwright et al., 1994). From the perspective of human factors, noise can affect performance by interfering with communications, interfering with sleep, and causing annoyance. The SpaceHab is a modular laboratory that fits in the cargo bay of the Space Shuttle. In an assessment of the SpaceHab-1 mission (STS-57), Mount et al. (1994) found that while the measured noise levels did not generally exceed the permitted levels for the shuttle flight deck or middeck, noise levels were substantially above design limits for the SpaceHab. This is probably because of the number and nature of experiments and equipment that were located there. However most crew members required earplugs during sleep, even though they slept in the Shuttle. Crew members principally used the intercom rather than unaided voice to communicate, even when in the same area, and reported difficulty in concentration and noise-induced headaches and fatigue.

Large space vehicles present a significant acoustics challenge because of obvious difficulties with controlling a number of connected, operating modules with payloads and equipment to perform vehicle functions and experiments, sustaining crew, and keeping them in good physical condition. Modules have equipment such as fans, pumps, compressors, avionics, and other noise producing hardware or systems to serve their functional and life support needs. Payload racks with operating equipment create continuous or intermittent noises, or combination of both. Payload rack contributions to the total on-orbit noise can be and has been shown to be significant. The crew exercises on a treadmill and with other conditioning devices, which generate noise. Communications between crew and ground, which are raised to communicate over the background environment, adds to the overall crew noise exposure. The crewmembers have to work and live in the resultant acoustic environment. The acoustics challenge is further complicated by the fact that there are numerous suppliers of modules, hardware, and payloads from across and outside the United States. (Goodman, 2003).

The Mir Audible Noise Measurement experiment was designed to characterize the Mir internal environment background noise levels during the docked period of STS-74 with Mir. The NC 50 curve was exceeded at all measurement locations except the Kvant 2 Airlock Compartment. During the docked time period, Mir science and exercise activity

was low. Overall, the crew's subjective impression of the Mir acoustic environment was favorable, however some hearing loss was noted at the end of the mission. (NASA, 1996)

The ISS is a complicated and sophisticated machine. ISS hardware is divided into categories including the module (or spacecraft), government furnished equipment, and payloads (science experiments). These different categories of hardware are governed by different requirements. Acoustic noise emissions verification is performed through actual test measurements of the hardware to the greatest extent possible. However, in some instances a fully integrated end-item is not available due to schedule mismatches, physical limitations to the hardware configuration or the payload may be delivered to ISS and placed in a rack already onboard. An acoustic test-correlated analytical model is used to predict overall noise levels in this case so that crew safety can be ensured. Remedial actions are performed to quiet hardware when necessary (Allen and Goodman, 2003).

Flight data was taken in the ISS in 2003. The U. S. Laboratory when first flown exceeded the NC-50 module requirement, before the payloads were factored in. The requirement was waived predicated on planned modification of three hardware items: the pump package assembly, the Carbon Dioxide Removal Assembly and the medium rate outage recorder. Two of these items have been modified, and the third modification is under assessment. With the addition of the payloads and science equipment the U.S. Lab is reasonably close to the total module systems requirement of NC-52, except noise level has been higher in the aft end of the module. The Node and Airlock are shown to be at acceptable levels. Measurements taken in the Russian modules - Functional Cargo Block, Service Module, and the Docking Compartment - exceed specification limits. Waivers have been granted with the intent to implement modifications as soon as feasible. Noise levels have improved but are still excessively high. The acoustic levels (measured in ground testing) of other ISS international partner modules are expected to be acceptable. (Goodman, 2003)

3.5 Lighting

Lighting is essential to performing virtually every task in space. When windows are present and unshuttered, the typical 90 minute low earth orbit of the Shuttle or Station cause problems with time for eyes to adapt to the rapid disappearance of sunlight. In the study by Mount et al. (1994) the most frequent report of lighting problems was that sunlight made electronic displays and video monitors difficult or impossible to read. However, some activities such as remote manipulator operations require out the window viewing, and Earth-watching is a favorite crew activity in any spare time. Wheelwright (1994) and the Man-Systems Integration Standards (NASA, 1995) provide tables and guidelines for illumination levels for various intravehicular and extravehicular tasks.

Two critical tasks requiring vision of external targets are docking the Shuttle to the ISS and using remote manipulators to position space-suited crewmembers or large structural components. In low earth orbit, there is a change from light to dark every 90 minutes. In vacuum, shadows are much sharper than in an atmosphere where water vapor, dust

particles and other airborne particles scatter light. To ensure adequate light, tasks may be scheduled to be performed in those parts of the orbit when the combination of sunlight and artificial light are predicted to provide adequate contrast and visibility. (Bowen, 2004) NASA developed software that models realistic images of complex environments. Measured data is used to develop models of shuttle and station artificial light. Natural lighting, such as sun and earthshine, are also incorporated into the lighting analyses. By incorporating the measured reflectance of each material into the lighting models, an accurate calculation of the amount of light entering a camera can be made. Using this calculated light distribution with the model of the shuttle cameras, camera images can be simulated accurately. Use of these lighting images are essential to predict available lighting during space operations requiring camera viewing, such as the assembly of ISS components. In preparing for a shuttle visit to ISS, mission planners simulate the lighting environment for critical tasks at 1-min intervals.

3.6 Dust and Debris

Debris and dust in the Orbiter Crew Compartment of early Shuttle missions created crew health concerns and physiological discomfort and was the cause of some equipment malfunctions. Debris from Orbiters during flight and processing was analyzed, quantified, and evaluated to determine its source. Selected ground support equipment and some Orbiter hardware were redesigned to preclude or reduce particularization/debris generation. New filters and access ports for cleaning were developed and added to most air-cooled avionics boxes. Most steps to reduce debris were completed before flight STS-26, in 1988. After these improvements were made there was improved crew compartment habitability and less potential for equipment malfunction (Goodman, 1992).

For future Lunar / Mars exploration missions, the problem of dust in these environments is recognized. However, our knowledge at this time is limited as to the specifics of the dust. We have some data from previous Lunar Missions and are supplementing it with derived data. Derived data from our limited, but growing, knowledge of Mars is forming a basis of our need for requirements for dust abatement. The dust will cause a serious problem for extravehicular activity (EVA) suits and equipment used external to the vehicle. There is also a concern for dust in the vehicle habitation area. Dust inside the vehicle could increase crew time due to more frequent filter changes and other chores to remove dust from equipment. Basic habitability could also be affected if the dust were to accumulate on display screens and cooking equipment.

4. HABITABILITY AND ARCHITECTURE

4.1 Architecture

Habitability as a discipline is concerned with providing a space vehicle that, within some understandably necessary size restraints, provides a comfortable, functionally efficient habitat that will support mixed crews living and working together for the duration of the mission. Attention must be given to the morale, comfort and health of crews with

differing backgrounds, cultures, and physical size. Architectural design of crew interfacing elements should be comfortable for the extremes of any crew population. The "Habitability Architecture" design concerns are mainly the fixed architectural elements such as (a) the geometric arrangements of compartments (b) passageways and traffic paths., (c) windows (d) color, (e) workstations, (f) off-duty areas, (g) stowage, (h) lighting. (NASA, 1983)

4.1.1 Compartments

The success of an extended mission on a space vehicle depends on the crew being an integral part of the interior design. Focus of any vehicle design should be crew-centered. The arrangement and design of any habitable compartment should take into account the possibility of a subsystem failure or damage that could require quick, efficient evacuation.

The actual vehicle arrangement is dependent on the specific program's goals and definition. Based on space flight history, configuration should take into account the following:

- Sleeping / private areas should be separate from traffic paths and noise generators.

- Areas that are to be used by more than one crewmember at a time should be arranged to avoid bottlenecks. These are areas such as galley, work stations, waste management systems, etc.

- Traffic flow analysis should be done for crew tasks and activities.

- Switches should be located in proximity of associated equipment.

- Adequate electrical outlets should be provided to reduce the use of extension power cords and the resulting 'spaghetti all over'.

- A dedicated desk/work area should be provided for general 'paper' work associated with vehicle keeping.

Skylab experience has shown that crewmembers were able to operate equipment easily from any orientation. Basically, a crewmember established a local orientation based on his/her self and proceeded without difficulty. However, it was also shown that crew could much more easily orient themselves in a room with equipment oriented with a consistent 'up' and 'down'. An inconsistent, "zero-g" orientation of one module caused orientation problems that were time consuming. The conclusion is that a common plane for visual reference should be designated throughout each module.

Habitable volume is defined as free, pressurized volume, excluding the space required for equipment, fixtures, furniture, etc. It does not include "nooks and crannies", i.e., spaces too small for human access. Total volume requirements are dependent upon the specific program goals of the particular mission. Volume requirements for specific workstations have to be determined after determination of the tasks required at the workstation and number of crew involved. (NASA, 1983)

4.1.2 Passageways and Traffic Paths

A passageway is defined as a pass-through area between two nonadjacent compartments. Passageways shall be kept free of sharp and protruding objects. Skylab crewmembers liked the large "ship type" doorways. They found round hatches to be much less satisfactory.

Traffic paths consist of three types; emergency, primary and secondary.

Emergency paths are those used for crew passage to emergency equipment such as oxygen bottle/mask, fire-fighting equipment, pressure controls and escape hatches.

Primary paths are those used for personnel/equipment transfer between major habitable compartments, or between a compartment and workstation or off-duty area.

Secondary paths provide access behind equipment, between equipment and structural members, and around workstations.

All of the above traffic paths can be superimposed to form a total traffic pattern, which in conjunction with detailed task analysis, can be used to determine the most efficient placement of mobility aids. This traffic pattern and task analysis must also be used to design out potential bottlenecks in a space vehicle.

To be avoided are the bottlenecks experienced on Skylab missions. They were:

- Insufficient passage room in areas with workstations

- Too much activity in one place e.g., conflicting placement of shower and tool kit.

- Inability to use the waste management equipment, if there was someone using the hand washing equipment. (NASA, 1983)

4.1.3 Windows

All habitable volumes should include windows that are adequate for terrestrial and celestial references. Windows are necessary for observation of scientific phenomena, monitoring of EVA, observation of the vehicle exterior, photography, and general viewing. Sufficient window locations should always be provided to view earth, both for Earth observation experiments and for crew recreation and well-being.

All viewing windows and the area adjacent to them should be considered a crew work station. Sufficient work space and restraint equipment should be provided at view ports for one or more crewmembers to perform assigned tasks. A window should be installed in the pressure hatch that allows the flight crew to observe the EVA crew in the airlock.

Windows that are to be utilized for special photography and scientific experiments must be designed with an aperture size that is compatible with the equipment and tasks specified for that location. Space flights have shown window gazing to be the prime off-duty activity for the crewmembers. Window viewing has been a treasured past-time on all missions to date.

The design of viewing windows should not impose difficult housekeeping tasks upon the crew. Cleaning equipment should be provided for removal of fingerprints and other stains

that may accumulate. The equipment must be compatible with the coating(s) on the window and not scratch or affect the optical quality of the window or disturb any surface coating.

Each window should have a sufficiently clear area around it to permit any body position for viewing. A positive means of defogging the windows should be provided. All window covers and/or shutters shall be operated by a device that is easy for any crew member to use. All viewing windows should be provided with a crew-operated, opaque sun shade located within the interior of the spacecraft that is capable of restricting all sunlight from entering the habitable compartments. (NASA, 1983)

4.1.4 Color

Color should be used to provide visual stimulation for the vehicle occupants and to create different moods for relieving the monotony of prolonged confinement. Factors required in color planning are: room volume, function, architecture materials, safety, and required color coding.

As the Skylab mission grew in length, the interior color scheme became less acceptable. The crew of the 84 day mission felt the color scheme was too drab and suggested that accent colors should be used more extensively.

Color coding should be used as a supplement to nomenclature to enhance discrimination and to assist the crew in rapid identification of functions.

Coding of EVA equipment should be used with colors that will not deteriorate from solar exposure. All EVA handrails should be a standard color. The color should have a high contrast ratio with the background. (NASA, 1983)

4.1.5 Workstations

A workstation is defined as any location in the space vehicle where a dedicated task or activity is performed exclusive of the recreation, personal maintenance, and sleep areas. Tasks and activities include

- Vehicle stabilization and control
- Systems management
- Experiments
- Science
- Maintenance (equipment repair)

With any workstation, analysis should be done to determine the tasks, operator activities, tools and equipment necessary for each workstation. To make efficient use of space, multi-use workstation can be considered.

All necessary equipment, tools, restraints, lights, and power outlets should be provided at

each workstation. Adequate space should be provided for the crew to perform the assigned tasks efficiently and safely. Where possible workstations and associated equipment should be standardized throughout the entire vehicle to aid in the efficiency of tasks. Part of the workstation analysis should cover adjacent workstations and any impact that might arise from two crew members working at adjacent workstations at the same time. An analysis of traffic flow should be completed to determine placement of a workstation without 'bottlenecks'.

Flight experience has shown that anything 'usable' will be used as a kickoff point or as a grabbing point to change direction of travel. All workstations should be planned to limit inadvertent control activation and/or deactivation by passing crewmembers.

A restraint system should be incorporated into a workstation design with compatibility to the task to be done. (NASA, 1983)

4.1.6 Off-duty Areas

There should be a dedicated area for off-duty activities, with a minimum space for the entire crew. This allows for socialization. Stowage areas should be provided in a dedicated recreation area and in the personal space area for items to be used during recreation activity and off-duty time. (NASA, 1983) There has been agreement from crewmembers on U.S. Missions and also from crew during analog studies that they do not like to have the same table used for dining as well as a maintenance bench and / or as a biology work area. (Mount, 2002)

4.1.7 Stowage

Stowage space must be provided. For efficient use the space should be near the stations where the stowed items will be used. A method should be provided for locating stowed equipment and supplies. This is extremely important for a mission like the International Space Station where crews are periodically changed out, but large quantities of the stowed equipment and supplies stay. (NASA, 1983)

4.1.8 Ambient Lighting

For the most part lighting follows the same requirements as an Earth structure. But, spacecraft hardware designers face a few human factors challenges not usually encountered in earthbound environments.

In general, design of any space vehicle must take into account the constraints of power and weight limitations. This has an impact on the number of lights and their specifications. General lighting for all vehicles designed and built in the U.S. Space Program have been fluorescent luminaires. New types of lighting are being considered, like LEDs. Fluorescent lighting has to be sealed to contain the mercury in case of breakage. The use of fixed luminaires for general illumination within the relatively small habitable volume of a

spacecraft implies that an astronaut may frequently find one or more of these light sources in her/his field of view as she/he floats in microgravity. This creates potential direct glare sources.

Additionally, many astronauts are old enough to have experienced typical symptoms of presbyopia. The loss of the full range of accommodation in their viewing close and distant objects is often simply compensated for by their use of corrective eyeglasses or contact lenses. These means are not available to an astronaut during extravehicular activities in a spacesuit, however. The dry, low-pressure, high-oxygen content environment within the spacesuit precludes the use of contact lenses, and the helmet does not provide adequate interior space for eyeglasses. If the helmet were roomy enough to allow eyeglasses to be worn, it is likely that internal light reflections between the lenses of the eyeglasses and the interior of the faceplate would prove problematic. This means that when planning an EVA task, lack of eye glasses and light levels must be taken into account. (Bowen, 2004)

While in low-earth orbit there is a change from light to dark every 90 minutes. This impacts the EVA task planning due to the changes in light and shadows. The Graphics Research and Analysis Facility at Johnson Space Center, uses an accurate lighting model to produce realistic images of this complex, ever-changing environment. Measured data is used to develop models of shuttle and station artificial lights along with the natural lighting from sun and earth shine. This information is incorporated into the task analysis for EVA tasks. (Maida, 2002)

4.2 Considerations for Self-Sustenance

The spacecraft must be designed to provide for all aspects of life. For long duration missions, private compartments are used for sleep and certain personal activities such as recreational reading or communicating with family and friends. Since the sleep compartment is the single location in which the crew member spends the most time, it has been found to be most effective to heavily shield the compartment against radiation.

4.2.1 Sleep

An individual sleep compartment should be provided for each crewmember. The private sleeping accommodations should have a privacy curtain, partitions and stowage lockers. Each sleep area should be located as far as possible from noise, activity and public area.

Since there is no up or down in weightlessness, the position of the body did not matter during sleep (Figure 3). Some astronauts have been bothered by an effect known as 'head nod'. If the head is not secure when fully relaxed during sleep the head develops a nodding motion. Astronauts can secure the sleep restraint (sleeping bag) to limit this nod. Skylab sleep restraints were similar to sleeping bags with neck holes and arm slits. Straps were on the front and back so the crewmember could be tightened for a steady, snug position.

The Space Shuttle missions sometimes split the crew into two shifts to enable around the clock science. Figure 4 shows the compartments provided for the off-duty crew's sleep. Figure 5 illustrates a non-standard sleep bag.

(Insert Figures 3, 4, and 5 about here)

4.2.2 Food

Since the first food was consumed in orbit in 1962, improvements and developments have been made and are continuing to be made in the food systems for manned space flight. The food system for the Mercury flights was limited in scope and purpose. Food was used in most cases to obtain general information on the effects of null gravity on food ingestion and digestion and to determine types of food and packaging for longer duration space flights. Food for Mercury flights consisted of purees in aluminum tubes, coated tubes, and rehydratables.

The Gemini food system began with an all dehydrated food system which provided four meals per day per crewman. This was later changed to three meals per day and a wider variety of food was supplied. The food consisted of bite-size cubes with an expanded variety and rehydratable foods which included beverages, pudding, soups, fruits and vegetables. The initial Apollo food system was based on the dehydrated system used for Gemini; however, greater attention was focused on astronaut preference. The availability of hot water increased the selection of foods and enhanced the palatability. The thermostabilized food in a flexible pouch, fresh bread, canned fruit and puddings, and frozen sandwiches for launch day were some of the items introduced on Apollo. Results from Apollo proved that food could be consumed from an open container using normal utensils in micro-gravity.

A completely new food system was designed for the Skylab program. The new system was required because:

1. the food was launched with the orbiting laboratory and would be exposed to unusual environmental extremes and long term on-orbit storage
2. the metabolic studies onboard required precise intakes of several nutrients
3. all water had to be launched, so rehydratables offered no weight advantage
4. refrigerators, freezers, and food warmers would be available.

In order to meet the long shelf-life requirement, all Skylab foods were packaged in full panel pull-out aluminum cans. Cabin pressure required that the aluminum cans be overcanned in canisters to withstand pressure variances. This resulted in the rehydratables being packaged in three containers - a plastic pouch, can, and canister. Beverages were

packaged in a polyethylene collapsible container, which expanded on reconstitution. Menus for Skylab were repeated every six days.

The Apollo-Soyuz Test Program (ASTP) food system maximized menu variety and incorporated the most acceptable food and packages developed for Apollo and Skylab with the mission constraints; i.e., no freezer or food warmer, limited weight and volume, and limited supply of hot water.

An ASTP type food system with some modification was used for the first four Shuttle flights. A carry-on-portable food warmer was used to heat foods to serving temperature since there was not hot water available. The Shuttle food system packages were introduced on STS-3 and STS-4 in test meals, and the fifth mission was all packaged in the Shuttle container. The container is an injection molded rigid base with a thermoformed flexible lid and a dehydration port. The package functions as a container for rehydratable foods as well as beverages. The Shuttle package was designed in conjunction with the galley, which provides a meal assembly and preparation area, some food storage, hot and cold water, and a forced air convection oven for warming food. The design of the Shuttle package significantly reduced the production process and eliminated numerous failure points. Most of the package production steps are automated or semi-automated. The Shuttle food system uses a portable food tray for assembly and consumption of meals. This concept was first tested on ASTP and has been used since.

At the present time research is ongoing to look into advanced technology for future food systems for Lunar and / or Mars long-term missions. This includes the growing of crops onboard a space vehicle.

Historically, food weight for U.S. space food systems has been dependent upon the water supply. When fuel cells are used, (as on the Shuttle) water as a by-product is available for use with the food. When solar panels are used, all water has to be launched, and the advantages of dehydrated foods are diminished. The weight varies from a completely dehydrated system of 1.7 lbs to the Skylab system with frozen foods and a weight of 4.2 lbs. Per person per day. Water is a necessity and must be provided either in the food or if the food is dehydrated then added back prior to consumption. When dehydrated food is used the original flavor is rarely attained when hydrated.

The type of food as classified by the method of preservation also influences the weight of the food system, the palatability and the preparation. Table 3 shows the support elements or activities associated with each classification of preservation. Most of the natural form foods such as cookies, dried fruits, etc. only require opening the package compared to the dehydrated foods which require six support elements.

The Shuttle food system was designed specifically for typical Shuttle missions which are usually around seven to ten days in length. Although the system works well for Shuttle, it would be deficient in several areas for longer missions. The primary packaging material will not protect the food if stored unrefrigerated for long periods. In addition, the foods

are packaged in single service containers which are an inefficient method storage for long duration missions. Although, the Shuttle packages only weigh one pound per person per day, this may be prohibitive for extended missions. The Shuttle single service packages also generate considerable amount of trash which could pose a problem over an extended time.

The Skylab food system was packaged and designed for long duration missions; however, little of the technology would be transferable due to the uniqueness of the metabolic studies which directed the food system design. Additionally, the Skylab food system was overpackaged and would be problematic on missions which are weight and volume critical.

(Insert Table 3 about here.)

The International Space Station (ISS) menu composition is an extension of the menu system established for the Shuttle/Mir Phase 1 program with consisted of 50% Russian and 50% American foods. For Mir, meals A and C were provided by Russia and the U.S. supplied meals B and D. Meal D was not considered a meal, but was a snack that could be eaten anytime during the day. Experience on Mir indicated that having Russian food for meals A and C resulted in little or no U.S. breakfast items. Conversely, commonauts did not get their usual snack items since the U.S. supplied these. A unique system that alternates these combinations every other day is used on ISS. Now the U.S. provides breakfast and lunch on one day and dinner and the snack the next day with Russia providing the other meals on the same rotation. Meal D is now called a snack and can be eaten anytime during the day. The menu format for Shuttle/Mir was a 6-day cycle while ISS is currently utilizing an 8-day cycle with plans to expand to a 10-12 day menu cycle in the future. The percentage of thermostabilized foods in the U.S. menu has constantly increased for the ISS food program. This is due to a higher preference by crewmembers for these items. (Kloeris and Bourland, 2003)

The next possible step after ISS is long-duration manned space flights beyond low Earth orbit. The duration of these missions may be as long as 2.5 years and will likely include a stay on a lunar or planetary surface. The primary goal of the food system in these long-duration exploratory missions is to provide the crew with a palatable, nutritious, and safe food system and minimize volume, mass, and waste. The paramount importance of the food system in a long-duration manned exploration mission should not be under-estimated. During long-duration space missions, several physiological effects may occur. They include weight loss, fluid shifts, dehydration, constipation, electrolyte imbalance, calcium loss, potassium loss, decreased red blood cell mass, and space motion sickness. The menu will provide the crew with changes in the nutrient levels that may be required due to the longer-duration mission.

The acceptability of the food system is of much greater importance due to the longer-mission durations and the partial energy intake that is often observed in space flight. The

decreased energy intake might significantly compromise the survival of the crew.

The food system will initially emphasize technologies for space-vehicle application (ISS and Shuttle) and then slowly focus on technologies toward tasks that support exploration. As the food system is developed, it must continually integrate and determine the impact on the air recovery, water recovery, biomass production, solid waste management, and thermal control systems. The needs and constraints of the other life-support elements must be balanced with the food system to provide a well-integrated life-support system for long-duration space missions. The food system will need to consider the availability of power, volume, and water availability as the entire food system is developed. (Perchonok and Bourland, 2002)

4.2.3 Personal hygiene

Managing personal waste and cleaning the skin and hair are problematic because of the lack of gravity and the cost of lifting water to orbit. Except for Skylab, dedicated volumes for various activities have been very limited. Early bodily waste management systems can be succinctly described as 'baggies'. Since Skylab, there have been a variety of suction-based toilets for collecting fecal matter and urine. The principle systems for personal hygiene for each major spacecraft are described below:

Skylab: Personal hygiene for the Skylab crewmembers was supported in the Waste Management Compartment (WMC). The WMC included: a fecal/urine collector; a handwasher; stowage for personal hygiene items and kits; and a drying station. There was also a shower aboard the Skylab. Pressurized water flow combined with a suction device to collect the water caused the water to flow 'down'. It was considered a pleasant experience but was very time consuming - about 45 minutes from start to finish. This included cleanup activity.

Mir: The Mir Personal Hygiene Subsystem consisted of toilets for body waste management; handwash units; a shower; and personal hygiene kits. For the last two years the shower was on board, it was used as an air shower (sauna). It was removed to make way for other required equipment.

Shuttle: For washing, the Shuttle crew is provided with Personal Hygiene System hose located in the Waste Collection System (WCS) compartment. Water is squirted onto a washcloth using the hose. Some crew prefer to use the hygiene port provided at the galley because it provides hot water. The hose for the galley hygiene port is long enough to be extended to the WCS for cleansing and grooming. The crew is provided with no-rinse body bath and no-rinse shampoo.

ISS: The Russian Segment is generally the same as Mir, without a shower. In the U.S. Segment the Personal Hygiene Subsystem provides a WMC. Wet wipes and towels are used from the Russian Segment. Occasionally ISS crewmembers have 'rigged up' a bathing device for their use. There are differing opinions on the results. (Mohanty, 2001)

4.2.4 Exercise

Exercise regimens prescribed for space missions have required gradually longer and more

frequent periods of exercise - particularly as the length of mission has increased. On the first prolonged (18-day) Soviet manned flight, Soyuz 9, physical exercises were performed by the cosmonauts for two one-hour periods each day. In subsequent 24-day flights, 2.5 hours of exercise per day was employed, including walking / running on a treadmill. By 1975, the standard program involved three exercise periods per day, with a variety of equipment for a total of 2.5 hours, with the selection of exercises on the fourth day being optional. Over the three missions of the Skylab program a similar increase in exercise quantity was imposed, although the total amounts were less than those used by the Soviets. On the last manned Skylab mission, a treadmill was provided which allowed more vigorous exercise.

Throughout the Skylab missions, successive improvements were seen in postflight leg strength and volume changes, orthostatic tolerance and recovery time, and cardiac output and stroke volume, even though each mission lasted four weeks longer than the last. Skylab 4, was a 84 day mission. Results of exercise on Soviet missions have shown a similar pattern of reduced physiological deconditioning in response to more strenuous exercise programs. (NASA, 1982)

The exercise requirement for ISS is 2.5 hours daily with 1.0 hrs for aerobic exercise (cycle ergometry or treadmill locomotion) and 1.5 hrs for resistive exercise conditioning. Each time segment includes 15 min for set-up and 15 for set-down of equipment. Usually, astronauts exercise 6 days/week, with day 7 as active rest (can exercise if they want to). They usually start exercise conditioning after space motion sickness has resolved and all transfer of payload has occurred. The Russians don't start exercise countermeasures until flight day 30.

The Shuttle requirements are different and depend on mission length and crewmember roles. They apply only to use of the cycle ergometer.

4.2.5 Recreation

With any space vehicle design for a long-term mission, an area for recreation should be designated to provide for social interaction, Earth-viewing, games, video tape viewing, music, and active and passive participatory activities. A quiet area should be provided for a crewmember to read, listen to music and write.

4.3 Vehicle Maintenance

With the exception of Skylab and ISS, in-flight maintenance provisions and planning on U.S. space programs have not been supported by definitive program requirements. The Skylab mission acknowledged a substantive role for maintenance to achieve mission objectives. The wisdom of this decision was validated by the major repair and maintenance tasks required during the brief lifetime of the program.

The Shuttle Program was to have no in-flight maintenance, with all maintenance tasks

planned to be done on the ground. Over the life of the program this has changed due to the necessity of preventive maintenance, even on the short missions, and unanticipated problems. (Mount, 1989)

On-orbit maintenance was recognized as an essential consideration within the International Space Station Program (NASA, June 2004). A three-tiered maintenance concept was adopted that is similar to that employed by military organizations. The primary mode of on-orbit maintenance was designated as Organizational Maintenance and consisted primarily of removal and replacement of Orbital Replaceable Units (ORU) (comparable to Line Replaceable Units in military applications). This was supplemented by *in situ* maintenance for systems that did not lend themselves to the modular ORU design approach. Examples would be utility lines and secondary structure. The option was retained for Intermediate Level maintenance that would consist of on-orbit repair of ORUs. Intermediate Level maintenance has been employed to a limited extent in applications such as replacement of circuit cards within avionics ORUs. Crewmember training for maintenance has focused on the development of general skills and on types of maintenance tasks. However, extensive training on highly specific actions is done in some specific instances.

Future missions will be challenged by their extended duration, limited or no resupply opportunities once the mission has begun, and extended round-trip communication times (Watson et al, 2003). These factors will require such missions to be almost entirely self-sufficient. An additional constraint will be the need to carefully control and minimize the mass and volume of equipment and supplies used to support maintenance activities. It is expected that maintenance will be performed at the level of piece-parts so that the required replacement parts will be as small as possible. However, performing maintenance at this level carries significant implications from multiple perspectives. First, hardware must be designed to enable crew members to perform the required maintenance. Not only must the equipment be accessible but it must also be possible for units to be disassembled as necessary to enable piece-part replacement. Additionally, commonality and standardization of piece-parts must be imposed to obtain mass and volume benefits. If not, then the number of unique piece-parts could be so great as to negate any potential benefit. This maintenance concept will also require more extensive diagnostic capabilities than used heretofore in space. Every effort should be made to incorporate these capabilities within the systems themselves to minimize the amount of standalone test equipment that is required. Preparation of all potential maintenance procedures in advance will probably be prohibitively expensive so means must be available to provide crewmembers with necessary information and guidance when needed. An attractive concept would be to have available the capability to automatically generate needed procedures based on input from diagnostic systems and from hardware design information stored onboard. Finally, maintenance at this level will require additional capabilities performing quality assurance tests. (Watson, 2004)

Future missions will likely require operations in multiple gravitational environments including the microgravity environment of Earth-orbit or in-space transit, lunar gravity

(approximately 0.17-g), and Martian gravity (approximately 0.38-g). Design for maintenance must take these environments into account. For example, a microgravity environment offers three-dimensional freedom of motion, facilitating access to all areas within a spacecraft volume. However, a microgravity environment introduces significant challenges from the standpoint of reacting forces that must typically be applied during maintenance tasks. Fractional-g environments will restrict mobility and access to some degree (for example, restricting access to hardware in overhead locations) but will facilitate the application of forces by crewmembers. Another subtle advantage to working in fractional-g environments is that unrestrained parts and tools remain where placed and do not tend to float away and become lost.(Watson, 2004)

With longer missions maintenance must be planned and all contingencies must be anticipated. Simple maintenance tasks take on great complexities when in micro-gravity. What might be considered a simple task on Earth, using a slot-head screw driver, could be impossible in Space. Automation is being developed to save crew time and increase productivity, but what are all the ramifications when the automation (and robotics) break down? (Mount, 1989) As automated capabilities become increasingly prominent in maintenance operations, the potential for their failure and appropriate fallback positions must be considered. Tasks and hardware for which robotic intervention is planned should retain manual intervention as a back-up capability. Designs should not preclude manual troubleshooting even if embedded diagnostics are planned. Interchangeability of hardware within spacecraft and among spacecraft should be a key design objective. (Watson, 2004)

Considerations to be given for support of maintenance in space fall into different categories: crew provisions, hardware, software, and supporting disciplines / processes.

Crew provisions:

- Crew interface at appropriate sites
- Personnel and equipment restraints
- Access - both physical and visual
- Work envelope (volume)
- Tools and task support equipment
- Procedural and reference data
- Suits and protective equipment

Hardware:

- Design for maintainability
- Redundancy in design
- Materials
- Fasteners
- Connectors
- Mounts
- Structural interfaces
- Sensors/instrumentation
- Piece parts / orbital replacement units (ORU's)

Software

- Architecture - subelement compatibility, maintainability, reconfigurability

- Automation, robotics and artificial intelligence
- Fault detection, isolation and recovery support
- Integrated computer assisted training support
- Inventory control and management
- Supporting disciplines / processes
 - Safety, reliability, maintainability and quality assurance
 - Configuration management
 - Configuration control
 - Configuration documentation
 - Configuration accounting

(Mount, 1989)

4.4 Restraints

Launch and reentry require significant structural strength; loads of up to 5 g's are experienced in nominal conditions. But once on orbit, the microgravity environment enables objects to be held in place with very little force – hook and loop fasteners dot the surfaces. On the other hand, some force must be provided to hold anything in place. Restraints are needed for both personnel and equipment in microgravity. The most common restraint for crew members is a foot restraint. For a location where a person will be working for extended periods of time, there are platforms that can be tilted to accommodate the neutral posture, with the feet angled down, and with height adjustments.

Tasks of different durations and requiring different degrees of force or dexterity require different types of restraints. Frequently short, easy tasks can be performed with toes stuck under a handle or one hand on a handhold. Tasks such as attaching a module to the ISS using the remote manipulator system, which take many hours and high precision of hand-eye coordination, require a restraint such as shown in Figure 6. This restraint provides support for the feet and the thighs. Another example of restraints is shown in Figure 7, illustrating use of existing hardware for a temporary restraint.

(Insert Figures 6 and 7 about here)

5. SLEEP AND CIRCADIAN RHYTHM

5.1 Sleep Shifting and Light

Circadian and sleep components, two physiological processes, interact in a dynamic manner to regulate changes in alertness, performance and timing of sleep. Light can aid in shifting circadian rhythms to an earlier or later time within the biological day. Also, use of bright light during nighttime can result in significant improvement in performance and alertness levels (Campbell, 1990) NASA currently uses light treatment to help crewmembers adapt their circadian system in before missions, allowing the astronauts to be physiologically alert when critical tasks are required. (Czeisler, 1999) The timed use of bright light to facilitate circadian phase shifts was effective in the STS-35 mission, the first mission requiring both dual shifts and a night launch. Subjective reports indicated that they were able to obtain better quality sleep during the day and remain more alert during the

night after using the bright light exposure to facilitate their schedule inversion prior to the launch dates. (Czeisler et al., 1999) Astronauts in space are exposed to variable light levels due to the non-24-hr orbital cycle (day/night) of space operations, such as the 90-min orbital cycle of the space shuttle. Additionally, light levels in the space environment can be variable. Field data have shown that light levels aboard spacecraft can be as low as 10 lux during the highest activity portions of the day and as high as 79,433 lux on the flight deck. (Dijk, 2001) The Soviets recommended 400-500 lux of full spectrum light for work on spacecraft and results demonstrated an improvement in performance when the location of lights on Salyut-7 was changed to maximize lighting (Bluth, 1984).

Around-the-clock operational tasks often require splitting crews into 2 separate shifts, necessitating half the crew to invert their sleep/wake cycles. A procedure called “slam shifting,” which involves abrupt shifts of up to 12-hr, is now used to align the sleep/wake schedules of Space Shuttle and ISS crews upon docking. Staggered sleep schedules on an 8-day mission did not work since the crew tended to retain ground-based work-rest cycles and the schedules resulted in increased fatigue and irritability. On a 1-yr flight, where sleep times for docking operations were shifted by 4.5 to 5.0-hr fourteen times, asthenia, end of day fatigue, and sleep disruptions were documented (Grigor'yev 1990).

Current astronaut crew scheduling guidelines allow for astronauts' schedules to be lengthened by no more than 2-hr (phase delay) and shortened by no more than 30-min (phase advance) within a given day. (NASA, 1992) Schedules can be lengthened only if there is an operational requirement. For example, if the shuttle is going to dock with ISS during a time that the ISS crew is scheduled to be sleeping, operations would require the ISS crew to shift to a new schedule in the days preceding, in order to be awake and alert for the docking. (Mallis and DeRoshia, 2003)

5.2 Mars day circadian entrainment

With NASA's continuing support of a manned mission to Mars, the effects of a Mars light/dark cycle must be investigated to determine the ability of the human to adapt to a Mars cycle and its impact on physiological alertness. The Martian day, otherwise known as a sol, is ~39-min longer than an Earth day (sol period= 24.6-hr). Although this period length is well within the circadian range of entrainment according to previous studies conducted in relatively bright light (23-27-hr) (Aschoff, 1981), preliminary laboratory results have suggested that in dim light conditions, such as found indoors, humans cannot reliably entrain to a 24.6-hr Mars sol. Individuals differ on their circadian rhythm, and the 25% of the population who have periods shorter than 24-hr will have the greatest challenges in entraining to a Mars sol. (Mallis and DeRoshia, 2003)

6. SELECTION

Today astronauts come from an international pool of candidates, including the European Space Agency, the Russian program, and the United States. Each country selects its own astronaut candidates according to that state's criteria. This section discusses the US

experience.

Planning the first astronaut selection in 1958, Dr. Allen O. Gamble, one of the psychologists on the medical team, realized there needed to be some job or task analyses. A difficult challenge, as no one had ever flown in space before. He listed the duties of the first astronauts as:

1. To survive; that is to demonstrate the ability of man to fly in space and return safely
2. To perform; that is, to demonstrate man's capacity to act usefully under conditions of space flight
3. To serve as backup for automatic controls and instrumentation; that is, to add reliability to the system
4. To serve as a scientific observer; that is, to go beyond what instruments and satellites can observe and report
5. To serve as an engineering observer and, acting as a true test pilot, to improve the flight system and its components. (Link, 1965)

Since the late 1950's there has always been some system of psychological selection, although there have been many changes in criteria and procedure. Originally, psychological assessment was extensive, requiring 30 hours of psychological testing, plus interviews and evaluation by a team made up of a psychiatrist, an industrial-organizational psychologist, and management.

In the 1960's the Lovelace clinic tested several women; 25 female pilots completed the same psychological evaluations as the males chosen for the Mercury project. Of these, 13 of them enrolled in an unofficial astronaut training program, none were declared as official astronaut candidates.

From 1958-1969, astronaut selection occurred at least 4 more times. Since applicants already had extensive flight experience, often hazardous, criteria emphasized emotional stability, motivation and energy, self-concept, and quality of interpersonal relationships. Psychological testing now required only 6.5 hours, and the clinical evaluation was primarily psychiatric rather than psychological. This shift toward clinical content paralleled a shift away from research, reducing the data available for systematic scientific selection into astronaut selection. By 1983, Jones and Annes (1983) could write, "Presently, no psychological testing is done." Instead, the evaluation consisted of two consulting psychiatrists who separately interviewed each candidate for two hours. This screening, although completed by expert aviation psychiatrists, did not have specific and objective criteria by which to rate each candidate.

After a hiatus of nine years, in 1978, astronaut selection began again for the space shuttle program, including non-aviators, scientists and women. It was not until the 1980's that NASA hired its own psychiatrist and soon thereafter, a psychologist to work in the operational arena. From 1988 through 1990, a newly established in-house group met to improve the selection process. This "Working Group on Psychiatric and Psychological

Selection of Astronauts” distinguished between the roles of psychology and psychiatry and rewrote NASA psychiatric standards to include disqualifying psychiatric disorders based on the then current American Psychiatric Association’s Diagnostic and Statistical Manual.

Holland (1999) notes that by 1989, clinical testing had returned, giving some objective data to be used by the psychiatrists, but it was still a medical model. By the 1994-95 selection cycle, non-medical evaluations based on industrial-organizational principles and techniques were added to the clinical and medical models. Based on these organizational studies, Galarza and Holland (1999) have listed the critical psychological proficiencies needed for space flight: “mental/emotional stability, ability to perform under stressful conditions, group living skills, teamwork skills, ability to cope with prolonged family separations, motivation, judgment/decision making, conscientiousness, communication skills, leadership capability. “

Currently, astronaut candidates complete an extensive battery of tests and undergo several hours of interview to determine their suitability. Interviewers undergo training and extensive review of their work.

7. CONCLUSION

After forty years of human space flight we have gathered great quantities of information dealing with the crew and their interfaces. With a new mission in front of us, going beyond low earth orbit, we must learn more about the challenges of long term missions. We must gather much more data from ISS missions. Additionally, we must take advantage of analogs that are consistent with the perceived challenges of long-term missions, and glean what we can to augment our knowledge base.

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CAPTIONS

Figure 1: Neutral postures in microgravity. Bodies 1-6 are actual crewmembers. Body 7 is a composite posture based on Skylab data.

Figure 2. A 95th percentile stature crew member is shown in a ‘neutral body posture’ (left) and standing vertically (right). The elliptical gray shading indicates the reach envelope. The darker gray cone indicates the viewing area.

Figure 3. Two examples of using the Shuttle Sleep Restraint while sleeping in the Shuttle mid-deck.

Figure 4. Shuttle sleep compartments are used when a crew is working multiple shifts during a flight.

Figure 5. A unique sleep restraint used by an ESA crewmember.

Figure 6. Operating the remote manipulator system requires a stable restraint, carefully adjusted.

Figure 7. Brief activities can be performed with simpler restraints.

TABLES

Table 1: United States crewed space programs to date. (NASA, 2003 and NASA, 2004b)

Program Name	Dates	U.S. Crew Size	Mission Length
Mercury	1961-1963	1	Up to 34 hours
Gemini	1961-1962	2	Up to 6 days
Apollo	1968-1972	3	Up to 12.5 days
Skylab	1973	3	Up to 84 days
Apollo-Soyuz (ASTP)	1975	3	Up to 9 days
Space Transportation System (STS)	1981-current	2 – 10	3 – 17 days
Shuttle-Mir	1995-1998	2 Russian, 1 US	Up to 6 months
International Space Station (ISS)	2000 - current	2 – 6 Including Int'l Partners	Approx 6 months

Table 2. Crew microgravity posture measurements, degrees. Crew 1-6 correspond to the body positions shown in Figure 1. Skylab Composite corresponds to illustration #7.

Anthropometric Measurement Joint Angles	Skylab Composite Left-Right	Crew 1 Left-Right	Crew 2 Left-Right	Crew 3 Left-Right	Crew 4 Left-Right	Crew 5 Left-Right	Crew 6 Left-Right
Hip flexion	50	33	33 - 29	33	33	29	12
Hip abduction	18.5	6.5 - 5.5	20 - 16	13 - 17.5	15.5 - 16	3.5 - 4.5	4 - 9
Knee flexion	50	50	83 - 87	50	50	44	11 - 12
Ankle plantar extension	21	6 - 7	15 - 14.5	29 - 30	27 - 24	16 - 14	35 - 41
Waist flexion	0	13	0	1	0	0	2
Neck flexion	24	16	18	16	5	7	16

Left neck lateral bend	0	0	0	3	0	0	0
Shoulder flexion	36	49 - 46	67 - 64	29	33 - 35	60 - 57	36
Shoulder abduction	50	32 - 33	26 - 26.5	27 - 29	40.5	24 - 45	23 - 36
Medial shoulder rotation	86.6	58 - 61	45.5 - 41	71 - 77	74.5 - 74	25.5 - 26.5	50 - 48
Elbow flexion	90	78	45 - 53	61 - 57	94 - 91	78 - 80	51 - 64
Wrist extension	0	0	3 - 0	0	0	0	0
Wrist ulnar bend	0	0	0	0	0 - 9	0 - 3	0
Forearm pronation	N/A	N/A	26	20 - N/A	N/A - 2	16 - N/A	N/A - 5
Forearm supination	30	7 - 10	N/A	N/A - 30	15 - N/A	N/A - 4	14 - N/A
Finger flexion	0	42	60	30	21 - 57	55 - 47	25 - 35

Measurements are in degrees. *Angles are based on an up right stature coordinate system.

Table 3: Types of food and associated equipment required. (NASA, 1983)

Food Type (method of preservation)	Equipment Required
Natural Form	Equipment to open package - if necessary
Thermostabilized, Irradiated	Method of heating Utensils Serving tray or dish Cleanup equipment
Frozen	Freezers Method of heating Utensils Serving tray or dish Cleanup equipment
Dehydrated (freeze dried, spray dried, etc.)	Hot and cold water Method to open package Method of heating Utensils Serving tray or dish Cleanup equipment